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Biogas Production from Maize Silage and Dairy Cattle Manure

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Abstract: Increase of world population and continuation of industrialization increase energy requirement. Meeting these requirements with fossil based fuels increase greenhouse gas emissions, cause environment-air pollution and global warming. Environment-friendly biogas output and utilization which decrease production input gains importance in meeting energy requirement in agricultural enterprises. Dairy cattle manure and maize silage are the common substrates for anaerobic digestion in agricultural enterprises. In this study, biogas production in anaerobic digestion is studied under mesophilic conditions for 60 days. Laboratory scale experiments were performed on the digestion of dairy cattle manure and maize silage at different mixing rate. The results showed that co-digestion of dairy cattle manure and maize silage have positive effects on biogas production and methane content of biogas. The highest biogas production was measured at the DM 6% content and the manure:silage rate 3:1. Also, the highest methane content was measured at the highest silage rate.

Key words: Anaerobic digestion, biogas, dairy cattle manure, maize silage, population

INTRODUCTION

Energy requirement has been increasing every day all over the world. Meeting these requirements with fossil fuels causes energy cost to rise. In addition to this, usage of current energy resources increase greenhouse gas emission and causes environment pollution have negative effect on global warming. As a result of this, interest and demand for alternative, renewable and clean energy resources and technologies have increased in recent years.

Anaerobic fermentation of organic material which is not only regarded as waste treatment method is a technique of production clean-renewable energy source of biogas. Methane-rich biogas is produced by anaerobic fermentation from various resources such as urban, industrial, agricultural resources. In recent years, biogas production from energy crops and animal manure has increasing importance throughout the world.

Co-digestion, i.e., the simultaneous digestion of a mixture of two or more substrates is a technique by which the bioconversion rate as well as the methane yield can be increased (Alvarez and Liden, 2009). Conventionally, in agriculture biogas production is based on the single fermentation of slurry, resulting only in small amounts of biogas. To enhance biogas yields plant biomass is increasingly added as co-ferment to agricultural biogas plants (Heiermann and Plochl, 2012). The economy of biogas plants can be improved by using high biogas potential substrates in combination with cattle dung (Satyanarayan *et al*., 2008).

One of the main problems in husbandry enterprises is the storage and disposal of animal waste. Methane emission which is one of the main reasons of global warming result from enteric fermentation and wastes in husbandry. Biogas production in anaerobic digestion in farm-scale units is used for producing domestic fuel and stabilizing animal waste for the use of digested manure as a fertilizer (Alvarez and Liden, 2009). Due to anaerobic fermentation of manure, its damages towards environment such as greenhouse gas emission decreases and fertilizer quality of fermented manure increases. Manure is also used as inoculation material in anaerobic fermentation.

Maize (*Zea mays* L.), herbage (Poacae), clover grass (Trifolium), Sudan grass (*Sorghum sudanense*), fodder beet (Beta vulgaris) and others may serve as energy crops (Amon *et al*., 2007; Chynoweth *et al*., 1993; Gunaseelan, 1997; Weiland, 2003; Tong *et al*., 1990). Among energy crops, maize is one of the most common

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substrates used in biogas production due to being compatible with mechanization and high methane yield per hectare.

MATERIALS AND METHODS

In the experiments, dairy cattle manure and maize silage were used. Dairy cattle manure and maize silage were obtained from a local farm close to Shenyang city (Li Xiang town, Yan Jia village) called Agricultural Park Dairy Farm which belongs to Liaoning Huishan Limited Company.

The manure was obtained from Holstein dairy cattle which are fed with maize silage, grass, fodder, etc. Maize silage was produced from whole plant maize (Northeast 510) cultivated in Shenyang (China) and ensiled. No additives for ensiling were applied. Inocolum was obtained from a working biogas plant which ferments dairy cattle manure in a local farm in Yan Jia village of Shenyang.

In this study, 2 important factors were considered. First factor; Manure:Silage mixture (M:S) rate, second factor: dry matter rate of the mixture. Mixture rates of manure:silage material are 1:1, 3:1 and 1:3, respectively. Each mixture was prepared in a way that dry matter rate would be 6 and 8% by diluting it with tap water according to their dry matter content. This solid content ratio referred to wet anaerobic fermentation. The substrates were used for anaerobic fermentation inoculated with liquid inoculum at the same proportion (30%).

N1, N2 and N3 treatments indicates that at the DM 6%, 1M:1S, 3M:1S and 1M:3S mixture ratio, respectively. N4, N5 and N6 treatments indicates that at the DM 8%, 1M:1S, 3M:1S and 1M:3S mixture ratio, respectively. Anaerobic fermentation experiments were carried out with 3 repetitions under mesophilic temperature conditions (37°C). The hydraulic retention time of the experiment was 60 days.

About 1 L glass bottles were used as anaerobic digester. Fermantation temperature was enabled with water bath whose temperature sensitivity is 0.1°C. In order to prevent formation of foam layer, all digester were mixed by shaking manually three times a day. pH measurement was done at each digester before anaerobic digestion experiments and pH was adjusted with chemical between 6.8-7.2 which is optimum for biogas.

Bottle's mouth was closed with a rubber stopper through which a glass tube was inserted for venting the biogas from the digester. Biogas coming out of the digester was collected continuously in a sampling bottle by the downward displacement of water. The biogas production was measured daily.

In order to analyze biogas, pattern channel was made on the digester biogas discharge pipe. The biogas was gathered in plastic gas bags whose maximum pressure is 3 kPa for checking the biogas composition. Biogas composition (CH_4, CO_2, H_2S, O_2, other) was analyzed with a biogas analyzer (Model: Biogas, Geotechnical Instrument Ltd. England). Methane and carbon dioxide is measured by infrared absorption. Oxygen and hydrogen sulfide is measured by chemical cell.

Prior to digestion substrates were analysed for Dry Matter (DM), Volatile Solid (VS), ash (XA), C:N ratio, crude protein (XP), starch (XS), sugar (XZ), crude fat (XL), Cellulose (Cel), hemi-cellulose (Hem), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Lignin (ADL), Kotassium (K), Phosphorus (P) with standard analysing procedures (AOAC, 2000). All analyses were performed by laboratory of Shenyang Agricultural University.

Statistical data analysis was carried out with the software package JMP 7 (SAS Institute Inc., 2012). Each treatment was measured in three replicates. One way Analysis of Variance (ANOVA) was performed on biogas production to test whether there was a significant effect of manure:silage rates and dry matter content.

RESULTS AND DISCUSSION

The results of analyses which were carried out in order to determine the properties of dairy cattle manure and maize silage used in this study were given in Table 1. Heiermann *et al.* (2009), Heiermann and Plochl (2012), Amon *et al.* (2011, 2007) and Banik and Nandi (2004) indicated the similar results about the characteristics of the substrates.

Raw material properties of substrates which are used in biogas production have important effect on the efficiency. Methane production from organic substrates

Table 1: The characteristics of the substrates

Parameters (DM %)	Dairy cattle manure	Maize silage
DM*	13.98	23.79
VS	82.75	93.57
XA	17.24	6.42
C:N	31.97	56.71
XP	15.4	9.91
XS	21.17	16.63
XZ	1.79	2.86
XL	3.11	3.17
Cel	21.84	28.42
Hem	22.69	26.62
NDF	61.26	64.80
ADF	38.74	38.23
ADL	11.97	6.96
K	0.38	0.40
P	0.10	0.37
pH	6.12	3.68

*FM %

mainly depends on their content of substances that can be degraded to CH_4 and CO_2. Composition and biodegradability are key factors for the methane yield from energy crops and animal manures. Crude protein, crude fat, crude fibre, cellulose, hemi-cellulose, starch and sugar markedly influence methane formation.

Animal diet influences methane efficiency and biogas production. Most of the biodegradable carbon in cattle feed is already digested in the rumen and in the gut. Thus, cattle manure has a lower potential to produce biogas than pig or poultry manure. CH_4 concentration in the biogas from cattle manure is lower (Weiland, 2001). Amon *et al.* (2007) indicated that the manures with the higher crude protein levels gave higher methane yields during anaerobic digestion. Lignin in the manure reduced the specific methane yield.

Type of maize, harvest time and technology and ensiling process have effect on biogas production and methane efficiency. The methane yield declined as the crop approaches full ripeness (Amon *et al.*, 2007). Anaerobic digestion requires a C:N ratio between 10 and 30. When the C:N ratio is too wide, carbon can not optimally be converted to CH_4 and the CH_4 production potential is not fully used. When maize was harvested at full ripeness, the C:N ratio was outside the optimum range with regard to producing a maximum specific methane yield. Co-digestion of substrates with a narrower C:N ratio could help to overcome this disadvantage (Amon *et al.*, 2007, 2011). Fermentation efficiency is raised by using substrates together. During the silaging process lactic acid, acetic acid, methanol, alcohols, formic acid, H^+ and CO_2 are formed. These products are important precursors for methane formation (Madigan *et al.*, 2000). Another reason for the increase in specific methane yield could be a predecomposition of crude fibre in course of the silaging process which improves the availability of nutrients for the methanogenic metabolism. Maximum methane yield is achieved from digestion of whole maize plants. Digesting corn-cob-mix, corns only or maize without corn and cob gives 43-70% less methane yield per hectare (Amon *et al.*, 2007, 2011). Experiments were terminated 60 days. Results for anaerobic fermentation experiment was given in Table 2.

In the experiment, maize silage's pH was very low for the digestion but manure's was suitable. Before the digestion, the mixed substrates pH was adjusted to 6.85-7.02 by using chemical. The final pH was found that 7.13-7.67. At the end of the 60 days the treatment N2 gave the highest biogas production. N6 and N3 treatments had the lowest biogas production. Biogas production shown in Fig. 1.

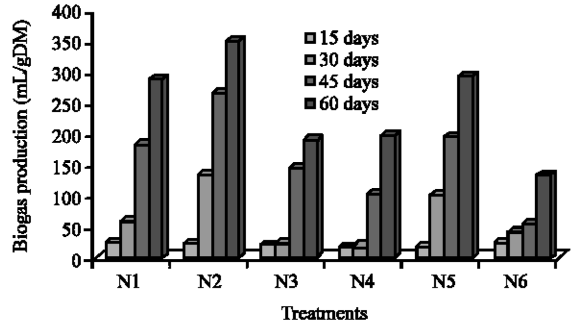

Fig. 1: Biogas production

Table 2: Results from anaerobic digestion experiments

Treatments	pH Initial	pH Final	Biogas production (mL gDM^{-1})	Biogas composition CH_4 (%)	CO_2 (%)	H_2S (ppm)
N1	6.95	7.65	289.29^b	69.63	19.86	0.00
N2	6.89	7.52	350.29^a	65.20	15.63	0.00
N3	7.02	7.57	192.46^c	71.70	12.03	0.00
N4	6.88	7.67	197.56^c	60.73	20.20	0.00
N5	6.90	7.57	292.80^b	60.63	21.50	0.00
N6	6.85	7.13	133.27^d	68.86	18.93	1.66

Different letters at the same coloum show significant differences at 0.05 level

Table 3: The effect of dry matter rates and manure: silage mixture rates on biogas production according to time

Treatments	Biogas production, Time (day): Interval 1 (1-15)	Interval 2 (16-30)	Interval 3 (31-45)	Interval 4 (46-60)
DM 6%	24.20$^{a\ NS}$	49.52^a **	124.82^a **	78.80$^{a\ NS}$
DM 8%	20.81$^{a\ NS}$	34.33^b **	62.54^b **	90.19$^{a\ NS}$
1M:1S	21.96$^{a\ NS}$	18.89^b **	101.69^a **	100.87^a **
3M:1S	22.22$^{a\ NS}$	96.03^a **	111.92^a **	91.36^a **
1M:3S	23.32$^{a\ NS}$	10.86^b **	67.42^b **	61.24^b **
Interactions				
DM 6% x 1M:1S	26.72$^{a\ NS}$	34.05^c **	121.76^a **	106.75^a *
DM 6% x 3M:1S	24.67$^{a\ NS}$	110.39^a **	131.48^a **	83.74^{ab} *
DM 6% x 1M:3S	21.20$^{a\ NS}$	4.13^d **	121.21^a **	45.91^c *
DM 8% x 1M:1S	17.21$^{a\ NS}$	3.73^d **	81.61^b **	95.00^{ab} *
DM 8% x 3M:1S	19.77$^{a\ NS}$	81.66^b **	92.36^b **	98.99^{ab} *
DM 8% x 1M:3S	25.44$^{a\ NS}$	17.60^{cd} **	13.64^c **	76.58^b *

*p<0.05, **p<0.01, NS = Not Significant

The CO_2 content in the biogas ranged from 12.03-21.5% and H_2S content in the biogas was very low. Despite low biogas production, the highest methane efficiency was found in N3. These results are compatible with the results of earlier studies (Heiermann and Plochl, 2012; Satyanarayan *et al.*, 2008). Earlier studies found that the nethane content 54-69% at the anaerobic digestion from maize silage (Heiermann and Plochl, 2012; Dubrovskis *et al.*, 2009). These results showed that using manure and maize silage as co-ferment increased the methane production.

Statistical analysis was carried out in order to determine the effect of different dry matter rates and manure: maize silage mixture rates on biogas production according to time (Table 3). The experiment time divided to four period. The highest biogas production was obtained between 31-45 days which is the 3rd time period. The results show that biogas production was highly influenced by dry matter rate in between 16-45 days of anaerobic fermentation. The effect of manure: silage mixture rate on biogas production is significant from the beginning of 16th day.

CONCLUSION

Anaerobic digestion should be economically efficient and optimise the environmental benefits. Usage of biogas decreases greenhouse gas emission which is the most important causes of global warming. In addition to this, enhancing the use of biogas as renewable energy source is an essential part for the development of energy farming. This will lead to new incomes for farmers. Usage of digestate for soil fertilization not only saves financial resources for farmers but also reduces the energy consumption.

The supply of a high quality feedstock is an essential prerequisite to obtain optimum gas yield. Maize silage and animal manures are very suitable substrates for anaerobic digestion. The addition of maize silage to conventional anaerobic digestion of dairy cattle manure causes a high gas yield.

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